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# **An Experimental Investigation of the Impact of Human Shadowing on Temporal Variation of Broadband Indoor Radio Channel Characteristics and System Performance**

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## **Abstract**

This paper reports the results of extensive measurements and analysis of the temporal variations of indoor radio propagation channel as a result of human traffic. The broadband measurements presented were taken at 5.2 GHz and were carried out in a large laboratory environment. Four antenna configurations were considered: for three sets of measurement the receiver used an omni directional antenna while at the transmitter omni, 60° and 90° antennas were employed. The fourth arrangement used a pair of 90° antennas at the transmitter and receiver.

The measurements also considered the performance of a multi-rate QPSK modem in terms of bit errors measured in the presence of human shadowing. The statistics of the received signal power, RMS delay spread and Rician K-factor are compared for the shadowing and static channel conditions.

## **1. Introduction**

The growth of mobile platforms and mobile communications, increased reliance of businesses on real time information exchange which leads to the need for the end users to have access in-building, at home, in public access locations, etc are all signs of the increased need for wireless communication.

Internet appliances, internet life style, digital devices that need to communicate (e.g. Hand held computing devices, Digital cameras, advanced telephony etc), increased penetration of home computing, multiple computers and peripherals are the trends at home which require wireless communication.

One of the traditional barriers to the adaptation of the wireless technology has been the standards,

interoperability and reliability of the devices on offer. The recent approval of the core technical specifications for the ETSI HIPERLAN type 2 standard in Europe and the efforts towards a global harmonisation of similar standards (IEEE 802.11 and the Japanese MMAC) will no doubt help the success of the wireless internet.

Indoor radio wave propagation characteristics clearly have a significant impact on the design of such systems and therefore numerous research activities around the world have been stimulated to gain detailed knowledge of radio propagation inside buildings.

The measurement and simulated data presented in published works often consider a static radio environment where there are no external disturbances to the radio channel. The corresponding descriptions of the multipath channels used therefore relate to the spatial variation of otherwise time invariant radio channel characteristics.

Temporal variations of the radio propagation channel that result from the movement of people and equipment in the environment are an important variation that should be considered in the design of indoor communication systems [1-4]. Temporal variations are particularly important considerations for the WLANs with an operational frequency in the millimetre bands (5 GHz and above) and they are designed to operate at relatively low transmission power.

It is therefore important to study the impact of temporal variation due to such disturbances in terms of the variation in the radio propagation parameters and also in the quality of service.

For this purpose a comprehensive campaign of measurements was conducted at the University of Bristol to analyse the influence of moving people on the radio bearer in the unlicensed 5.2 GHz band that has been specifically allocated to wireless LANs.

## 2. Description of measurements

The measurement system employed was configured to acquire the data for both wideband channel sounding and the bit error rate measurements of a multi-rate QPSK modem. The wideband channel sounder was based on the sliding correlator technique. The multi-rate QPSK modem was able to switch between 1.625, 6.5 and 26 Mbps. Both measurements were performed consecutively within the coherence time of the channel, using a single pair of antennas.

The measurement campaign also considered the impact of antenna directionality on the characteristics of the indoor radio propagation in the presence of human traffic.

The site for the measurements described in this paper was the undergraduate laboratory of the Electronic Engineering Department at the University of Bristol. The laboratory is situated on the ground floor of a four-storey building. The building structure is brick and concrete with large metal-framed windows. The floor in the laboratory is covered by wooden floorboards. The laboratory occupies an area of  $35 \times 13.4 \text{ m}^2$  (5m high ceiling), symmetrically divided into two rows of workbenches across the room with a corridor through the centre. The furniture in the room consists of metal benches loaded with typical test equipments on one side and computers on the other. Figure 1 shows a schematic diagram of the laboratory layout. A car park area is situated along the length of the lab on one side, while the other side overlooks an open area. The single glaze, steel-framed windows on both sides of the lab have dimensions of  $2.4 \times 3 \text{ m}^2$  (3cm frame and 3mm glass thickness). The windows are separated by exterior walls of 1.3m wide and thickness of 60cm giving a window to wall ratio of about 2:1.

The measurement system was configured to acquire the data for both the channel sounding and the Bit Error Rate measurements within the coherence time of the channel to enable direct statistical analysis of the channel parameter variations and their impact on the bit errors observed. The channel sounder employed for the measurements used the sliding correlator technique [5] with a 511bits PN sequence clocked at 100MHz. The centre frequency was 5.2GHz. The dynamic range of the sounder was 30dB and the transmit power was +5dBm. Details of the measurement equipment are described in [6-7].

Each dataset was collected over a period of 80 minutes with a sampling interval of 2 minutes. At each sample interval 5 snapshots of the channel (spaced by 0.1sec) were recorded in order to evaluate the local standard deviation. The omni directional transmitter (TX) antenna was placed at a height of 2.1m while the receiver (RX) antenna was at the desk level at 1.3m. Locations of the TX-RX antennas are marked as TX1-RX1 and TX2-RX2

in figure1. Partial line of sight was maintained between the TX-RX antennas throughout the measurements.

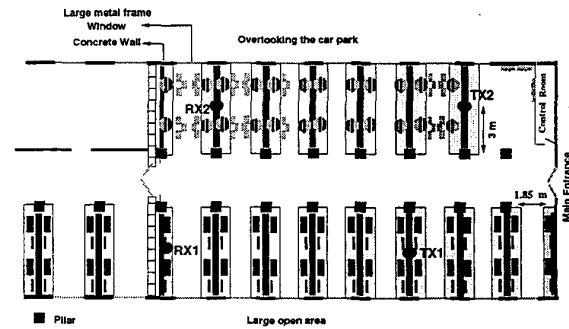
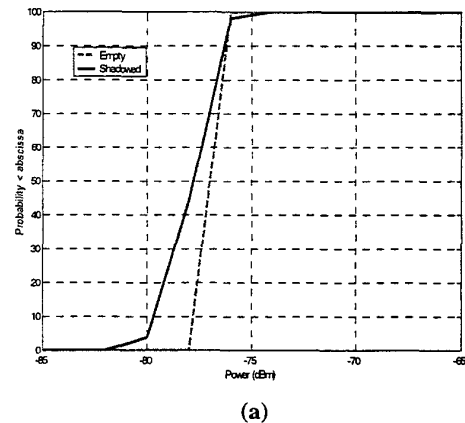


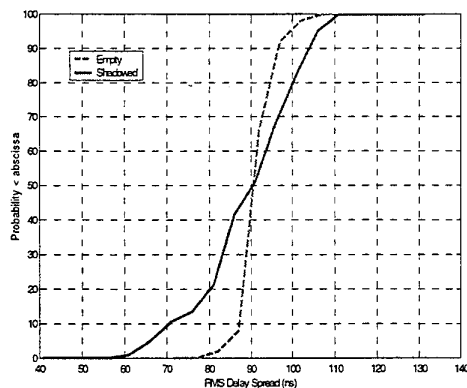
Figure 1 – Schematic Diagram of the Measurement Environment

## 3. Data analysis

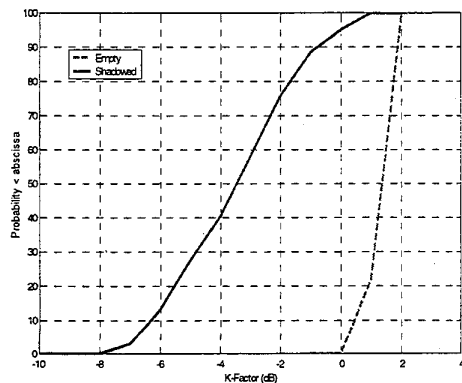
The results presented in this section were recorded during undergraduate laboratory experimental sessions with approximately 80 people present in the measurement environment, some of whom were moving between the TX and RX antennas (TX1-RX1 position). The shadowing instances were due to natural activity of the people within the environment and therefore the results are indications of real life variations experienced by the system.

Figures 2(a-c) compare the cumulative distributions of the channel parameters for an omni directional link for both static and shadowing situations. It can be seen from figure 2(a) that shadowing has caused a slight decrease in the received signal strength with the average power attenuated by 1dB compared to the empty scenario.





(b)



(c)

**Figure 2 – CDF of channel parameters for an Omni directional link**

**a) Received Signal Strength**

**b) RMS Delay Spread and c) K-factor**

The effect on the RMS delay spread is more interesting. From figure 2(b) it can be seen that 50% of the shadowing measurement instances show a reduction in the instantaneous delay values. However the range of the instantaneous delay spread values has greatly increased in presence of the human traffic (60 - 110ns, compared to 80 - 100ns range for the empty scenario). Figure 2(c) shows a similar comparison for the K-factor. The channel K-factor seems to be the parameter mostly affected by shadowing. The average value recorded for the shadowing scenario showed 4 dB reduction. Limits of the shadowing values have also greatly increased (-7 to 0 dB, compared to 0 to 2 dB for the empty case).

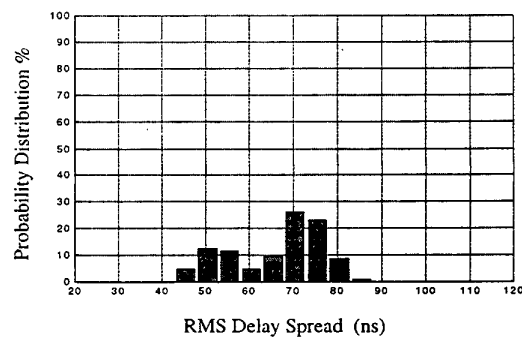
The measurement campaign considered two shadowing scenarios. For scenario 1, the human traffic in the environment was mainly in the vicinity of the TX-RX set up (position TX1-RX1 in figure 1) while for scenario 2

the TX-RX antennas were moved to position 2 which allowed the movement of people to take place mostly *between* the TX-RX set up. In both cases, similar densities of people were present in the environment.

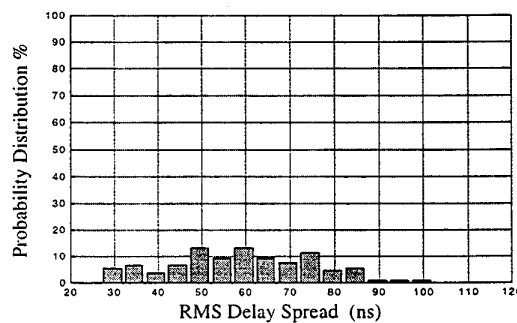
Figures 3 (a-b) and 4 (a-b) compare the probability distributions of the RMS delay spread of the empty and shadowed measurements for the two scenarios described. In both cases, shadowing has resulted in a larger spread of measured delay values. A similar observation was also made for the K-factor values calculated.

Movement of people between the TX-RX antennas (scenario 2) appears to have resulted in an increase in the delay values measured as one would expect. However the results presented in figure 3 where the shadowing was not directly between the antennas has in fact revealed a reduction in the delay spread values for some of the measurement instances.

An analysis of the K-factor values calculated for the scenarios 1 and 2 also indicate that in case of scenario 2 there is a clear reduction in K-factor in the presence of human shadowing while for scenario 1 the K-factor has improved for some of the measurement instances.



(a)

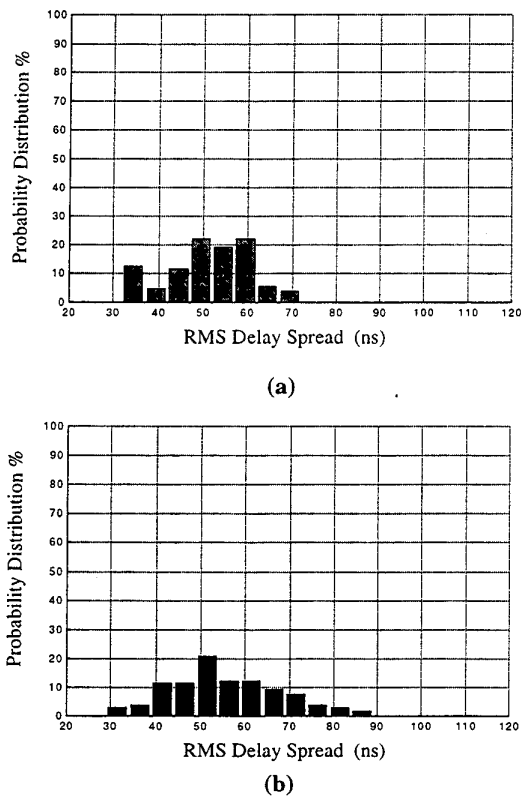


(b)

**Figure 3- RMS Delay Spread probability distribution function comparisons for the shadowing scenario 1**

**a) Empty environment**

**b) Shadowing in the vicinity of the TX-RX setup**



**Figure 4- RMS Delay Spread probability distribution function comparisons for the shadowing scenario 2**  
a) Empty environment  
b) Shadowing between the TX-RX setup

Table 1 compares the performance of the link for different data rates, based on the received bits in error exceeding 10% of the total transmitted bits over the entire measurement duration (80 minutes). It can be seen that channel disturbance as the result of human traffic can severely degrade the quality of the transmission.

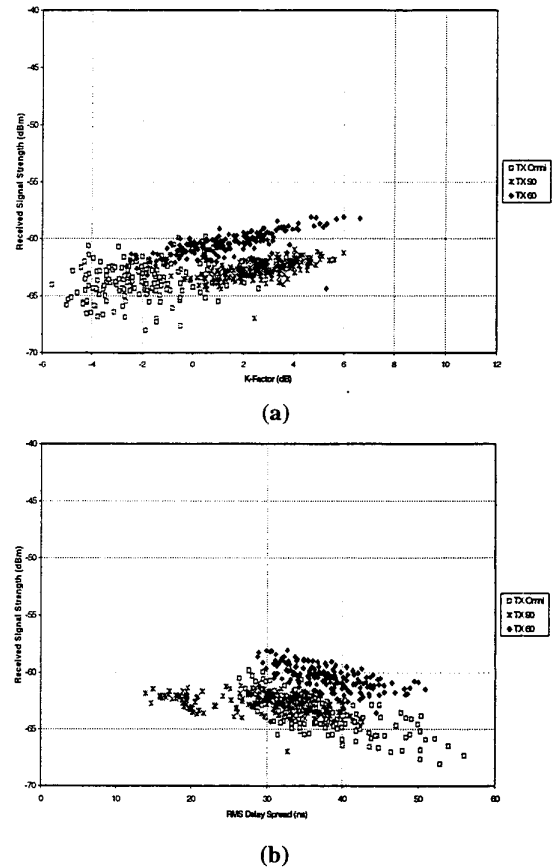
	1.625 Mbps	6.5 Mbps	26 Mbps
Empty	0%	0%	3.3%
Shadowing	11%	81.9%	83.8%

**Table 1 - Comparison of the performance measurement results**

In order to study the effect of using directional antennas a number of scenarios were considered for situations where just the TX or both the TX and RX antennas were directional. The results presented in figure 5 compare variations in channel parameters for

measurements made with an omni RX antenna in combination with omni, 90° and 60° TX antennas.

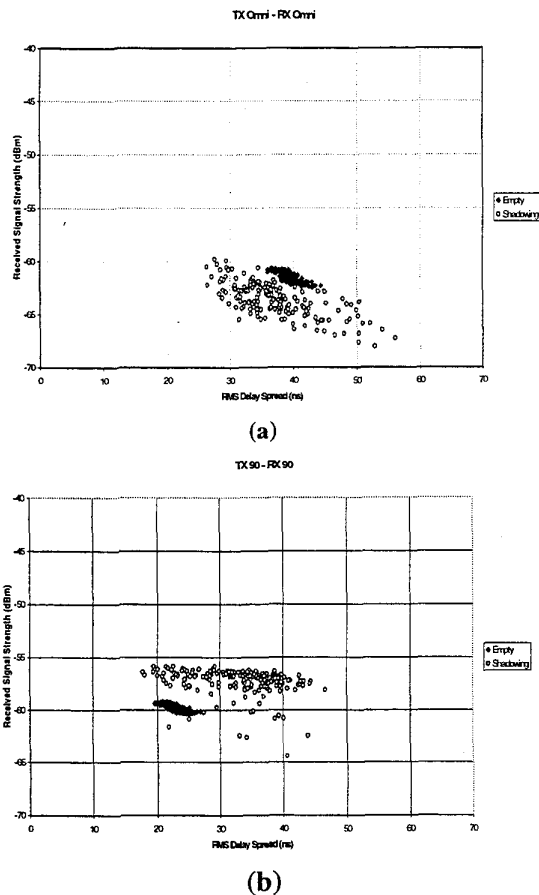
Figure 5(a) shows plots of received signal strength against K-factor. Figure 5(b) depicts the received signal strength against RMS delay spread. The shadowing condition for these measurements were as described for scenario 2 (shadowing between the TX-RX setup). It seems that the more directional link (i.e. the omni-60°) is more sensitive to the shadowing effect than the omni-90°, since the delay spread values measured with this arrangement are higher (by an average of 10ns) and suffer from larger fluctuations than the omni-90° combination. The calculated K-factor is lower for the omni-60 arrangement (by an average of 1dB) and also shows more variation. The results also clearly indicate that the omni-omni arrangement results in the highest delay spread values as well as lowest K-factor while the instantaneous variation in these parameters is also higher than the directional arrangements.



**Figure 5 - Channel parameter comparisons for Omni, 90° and 60° transmit antennas**  
a) Received Signal Power vs. K-factor  
b) Received Signal Power vs. RMS Delay

Figure 6 illustrates the measurements taken for the case when both antennas were  $90^\circ$ . Comparisons are also made with the omni directional link.

The results refer to the measurements for the shadowing scenario 1 (shadowing in the vicinity of the TX-RX setup), the antenna heights remained unchanged. Figure 6(a) shows comparisons of the recorded received signal strength against RMS delay spread for the omni directional link. Figure 6(b) shows a similar comparison for the  $90^\circ$ - $90^\circ$  arrangement. Figure 7 shows the comparison of RMS delay spread against K-factor for the two antenna arrangements.



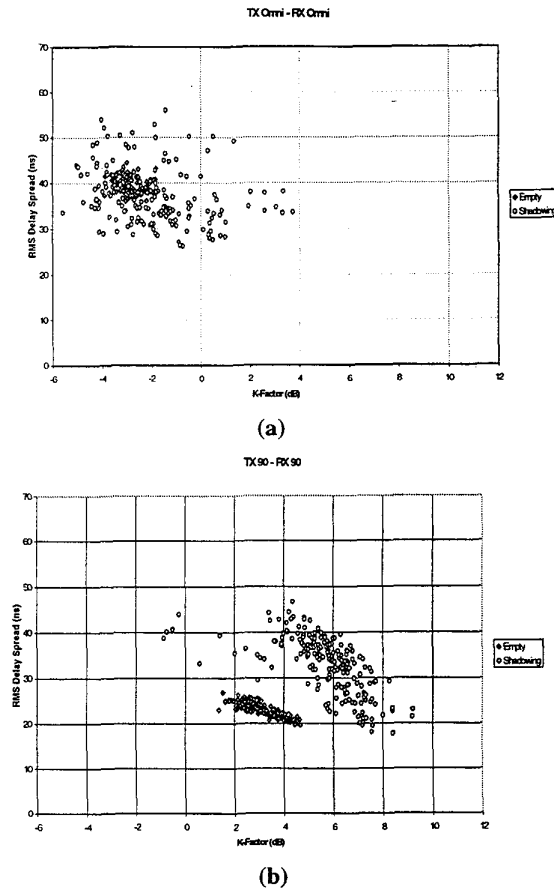
**Figure 6- Received signal strength vs. RMS Delay Spread for the empty and shadowing scenario 1**

- a) Omni directional antenna pair
- b)  $90^\circ$  antenna pair

The effect of spatial filtering on reducing the multipath can be clearly seen for the  $90^\circ$ - $90^\circ$  arrangement in case of static channel measurements. This has been shown more comprehensively for the static channel conditions in [7-8].

More importantly, the directional link appears to be less sensitive to the movement of people in the vicinity of the T-R antennas.

Table 2 summarises the statistics of the channel parameters for the omni-omni and  $90^\circ$  -  $90^\circ$  configurations. It can be seen that the average rms delay spread for the shadowing case increased by 10ns for the  $90^\circ$  -  $90^\circ$  while the average K-factor improved by 3dB. This represents a significant reduction in the multipath nature of the channel.



**Figure 7- RMS Delay Spread vs. K-Factor for empty and shadowing scenario 1**  
a) Omni directional antenna pair  
b)  $90^\circ$  antenna pair

The measured data suggests that for the omni directional link the average received signal strength decreased by 2-3 dB in the presence of human shadowing. This was not the case for the directional links.

		Omni - Omni Empty	Omni - Omni Shadowing	90° - 90° Empty	90° - 90° Shadowing
Received Signal Strength (dBm)	Average	-61.5	-63	-60	-57
	STD	0.5	1	0.4	2
	Deviation				
	Max.	-61	-60	-59	-56
K - Factor (dB)	Min.	-62.5	-68	-60	-64
	Average	-3	-1.5	3	6
	STD	0.4	2	0.8	2
	Deviation				
RMS Delay Spread (ns)	Max.	-2	4	5	9
	Min.	-4	-5.5	1	-1
	Average	40	37	23	33
	STD	2	6	2	6
	Deviation				
	Max.	44	56	27	47
	Min.	36	26	20	18

**Table 2 – Comparison of the channel parameter statistics for the Omni and 90° antenna pairs**

#### 4. Conclusions

Results of 5.2GHz propagation and bit error performance measurements in the presence of human shadowing have been presented for an indoor environment. It was shown that shadowing significantly increases the short term variations of the channel, which subsequently impairs the performance of the system. The degradation in the quality of the channel for shadowing conditions was shown in terms of the increased bit errors for three transmission rates using a single carrier QPSK modem. It appears that human traffic in the vicinity of the TX-RX antennas could in fact improve the multipath characteristics of the channel. The directional link also seems to be less prone to short time variations of the channel than the omni directional link under such conditions. On the other hand the movement of people between the T-R set up appears to have an opposite effect, resulting in degradation in the average measured channel parameters. The results provide a better understanding of the effects of human shadowing on the characteristics of the indoor radio channel much needed for more accurate modelling of practical indoor radio channels.

#### 5. Acknowledgement

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